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Attestation

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The attached documents are exact copies of the European patent application described on the following page, as originally filed.

Les documents fixés à cette attestation sont conformes à la version initialement déposée de la demande de brevet européen spécifiée à la page suivante.

Patentanmeldung Nr. **Patent application No.** **Demande de brevet n°**

01304489.6

Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
p.o.

I.L.C. HATTEN-HECKMAN

DEN HAAG, DEN
THE HAGUE, 16/08/01
LA HAYE, LE

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Blatt 2 der Bescheinigung
Sheet 2 of the certificate
Page 2 de l'attestation

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ASM LITHOGRAPHY B.V.
5503 LA Veldhoven
NETHERLANDS

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Particle shield, mask handling apparatus, lithographic projection apparatus, device manufacturing method and device manufactured thereby

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PARTICLE SHIELD, MASK HANDLING APPARATUS, LITHOGRAPHIC PROJECTION APPARATUS, DEVICE MANUFACTURING METHOD AND DEVICE MANUFACTURED THEREBY

The present invention relates to particle shields, e.g. for preventing contaminant particles from reaching a mask. More particularly, the invention relates to the application of such particle shields in mask handling apparatus, mask storage boxes and/or in lithographic projection apparatus comprising:

a radiation system for supplying a projection beam of radiation;

a support structure for supporting patterning means, the patterning means serving to pattern the projection beam according to a desired pattern;

a substrate table for holding a substrate; and

a projection system for projecting the patterned beam onto a target portion of the substrate.

The term "patterning means" as here employed should be broadly interpreted as referring to means which can be used to endow an incoming radiation beam with a patterned cross section, corresponding to a pattern which is to be created in a target portion of the substrate. The term "light valve" can also be used in this context. Generally, the said pattern will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit or other device (see below). Examples of such patterning means include:

- A mask. The concept of a mask is well known in lithography, and it includes mask types such as binary, alternating phase shift, and attenuated phase shift, as well as various hybrid mask types. Placement of such a mask in the radiation beam causes selective transmission (in the case of a transmissive mask) or reflection (in the case of a reflective mask) of the radiation impinging on the mask, according to the pattern on the mask. In the case of a mask, the support structure will generally be a mask table, which ensures that the mask can be held at a desired position in the incoming radiation beam, and that it can be moved relative to the beam if so desired.
- A programmable mirror array. An example of such a device is a matrix addressable surface having a viscoelastic control layer and a reflective surface. The basic principle behind such an apparatus is that (for example) addressed areas of the reflective surface reflect incident light as diffracted light, whereas unaddressed areas reflect incident light as

undiffracted light. Using an appropriate filter, the said undiffracted light can be filtered out of the reflected beam, leaving only the diffracted light behind; in this manner, the beam becomes patterned according to the addressing pattern of the matrix addressable surface. The required matrix addressing can be performed using suitable electronic means. More information on such mirror arrays can be gleaned, for example, from United States Patents US 5,296,891 and US 5,523,193, which are incorporated herein by reference. In the case of a programmable mirror array, the said support structure may be embodied as a frame or table, for example, which may be fixed or movable as required.

- A programmable LCD array. An example of such a construction is given in United States Patent US 5,229,872, which is incorporated herein by reference. As above, the support structure in this case may be embodied as a frame or table, for example, which may be fixed or movable as required.

For purposes of simplicity, the rest of this text may, at certain locations, specifically direct itself to examples involving a mask and mask table; however, the general principles discussed in such instances should be seen in the broader context of the patterning means as here above set forth.

Lithographic projection apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, the patterning means may generate a circuit pattern corresponding to an individual layer of the IC. This pattern can be imaged onto a target portion (*e.g.* comprising one or more dies) on a substrate (silicon wafer) which has been coated with a layer of radiation sensitive material (resist). In general, a single wafer will contain a whole network of adjacent target portions, which are successively irradiated via the projection system, one at a time. In current apparatus, employing patterning by a mask on a mask table, a distinction can be made between two different types of machine. In one type of lithographic projection apparatus, each target portion is irradiated by exposing the entire mask pattern onto the target portion in one go. Such an apparatus is commonly referred to as a wafer stepper. In an alternative apparatus - commonly referred to as a step-and-scan apparatus - each target portion is irradiated by progressively scanning the mask pattern under the projection beam in a given reference direction (the "scanning" direction) while synchronously scanning the substrate table parallel or anti-parallel to this direction; since, in general, the projection system will have a magnification factor M (generally < 1), the speed V at which the substrate table is scanned will be a factor M times that at which the mask table is scanned. More information with regard to lithographic devices as here described can be gleaned, for example, from US 6,046,792, incorporated herein by reference.

In a manufacturing process using a lithographic projection apparatus, a pattern (e.g. in a mask) is imaged onto a substrate which is at least partially covered by a layer of radiation sensitive material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as

priming, resist coating and a soft bake. After exposure, the substrate may be subjected to other procedures, such as a post exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to pattern an individual layer of a device, e.g. an IC. Such a patterned layer may then undergo various processes such as etching, ion implantation (doping), metallization, oxidation, chemo-mechanical polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure or a variant thereof, will have to be repeated for each new layer. Eventually, an array of devices will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or sawing, whence the individual devices can be mounted on a carrier, connected to pins, etc. Further information regarding such processes can be obtained, for example, from the book *Microchip Fabrication: A Practical Guide to Semiconductor Processing*, Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997, ISBN 0-07-067250-4, incorporated herein by reference.

In a lithographic projection apparatus, it is necessary to prevent any stray particles, which may be present in the apparatus from reaching, and becoming stuck to, the mask as they will then be imaged on the substrate and can be printed in the final device. Too high a level of contamination of the mask can lead to defective devices and the masks cannot generally be cleaned, or if cleanable can only be cleaned a limited number of times. In a lithographic projection apparatus using relatively long wavelength ultraviolet radiation, particles are prevented from reaching the mask by a pellicle. A pellicle is a thin membrane transparent to the radiation used in the projection beam of the lithographic apparatus and located parallel to but spaced from the mask. Contaminant particles moving towards the mask contact and stick to the pellicle. To ensure that the particles stuck to the pellicle are not printed on the substrate, the pellicle is spaced from the mask by a distance greater than the depth of focus at mask level.

However, it is not at present possible to provide a pellicle in a lithographic projection apparatus using UV radiation of 193nm or 157nm or extreme ultraviolet radiation for the exposure beam. Almost all materials are strongly absorptive of EUV radiation and a conventional membrane pellicle would have to be no more than about 30nm thick in order not to cause unacceptable absorption of the projection beam. A membrane of this thickness would not have a sufficient lifetime in both a vacuum, during operation of the apparatus and atmospheric environment, during installation and service. Other stresses, such as optical stress and temperature variance would also likely destroy such a thin membrane very quickly.

An alternative approach to a separate pellicle membrane is to form a cap layer, again transparent to the exposure radiation, directly onto the mask. To be effective, the cap layer would

need to be thicker than the depth of focus at mask level. The depth of focus at mask level is given by:

$$DOF = k_2 \cdot \frac{\lambda}{NA^2} \cdot \frac{1}{M^2} \qquad (1)$$

where λ is the wavelength of the EUV radiation, NA the numerical aperture at wafer level, M the magnification of the projection optics and k_2 a constant which is typically near 1. For EUV radiation of 13.5nm, a numerical aperture of 0.25 and a magnification M of 1/5, the depth of focus at mask level is approximately 2.7µm. The effect of such a layer on an EUV projection beam would be excessive. The transmission, *T*, of radiation through a material with thickness *d* is given by:

$$T = \exp\left(-\frac{d}{a}\right) \qquad (2)$$

where *a* is the attenuation length of the material (i.e. the length over which the intensity drops by a factor of 1/e). Even for a material which is relatively transparent to radiation at 13.5nm, the attenuation length is about 0.6µm. Accordingly, a cap layer of thickness 2.7µm would absorb about 99% of all EUV radiation.

Furthermore, when shorter wavelength radiation is used for the projection beam, the sensitivity to contaminants is increased. At EUV wavelengths, a contaminant particle of only 50nm diameter can lead to a faulty image. The need to keep the mask and other optical elements clear of contaminant particles is therefore extremely great.

It is an object of the present invention to provide a particle shield which is effective in mask handling apparatus and a lithographic projection apparatus using radiation of wavelength less than 200nm, and especially extreme ultraviolet radiation, to prevent particles reaching the mask or any other component which requires protection from contamination, whilst avoiding unacceptable attenuation of the projection beam.

According to the present invention there is provided a lithographic projection apparatus comprising:

a radiation system for supplying a projection beam of radiation;

a support structure for supporting patterning means, the patterning means serving to pattern the projection beam according to a devised pattern;

a substrate table for holding a substrate; and

a projection system for projecting the patterned beam onto a target portion of the substrate; characterized by

particle shield means for generating an electromagnetic field to deflect particles approaching an object to be shielded.

The particle shield means may generate a substantially uniform (purely) electric field, generally transverse to the direction of particles approaching the shielded object, so as to exert a force on all charged particles which will deflect them away from the object to be shielded. Although such a uniform electric field will not deflect neutral particles, the radiation of the projection beam in a lithographic apparatus, which is the principle source of energy for airborne particles in a lithographic apparatus, is strongly ionizing so that any particles likely to cause problems will almost certainly be charged and will generally have a charge many times the charge of an electron. A substantially uniform electric field can conveniently be generated using a capacitor like arrangement of conductive plates.

The particle shield may, alternatively or in addition, generate a non-uniform electric field so as to induce a dipole moment in neutral particles and then attract those particles in addition to charged particles. A non-uniform electric field can conveniently be generated using a charged elongate member.

The particle shield may further generate an alternating, or other time varying field, instead of or in addition to the uniform or non-uniform static fields.

The particle shield may also, again alternatively or in addition to the uniform or non-uniform electric fields, generate a transverse radiation beam (i.e. oscillating electric and magnetic fields), or optical breeze, which will transfer transverse momentum to particles entering the transverse beam and absorbing photons from it. The radiation wavelength can be chosen so as to be absorbed by all expected particles but not expose the resist should any stray radiation reach substrate level.

The particle shield can also be a radiation source directing ionizing radiation, e.g. suitably short wavelength electromagnetic radiation or an electron beam, across the front of the object to be shielded. With such an arrangement the object to be shielded can be charged positively, to repel positively charged ions, compared to its surroundings, and/or relatively negative collection plates can be provided to attract positively charged ions. This arrangement ensures protection of the object to be shielded even when the main projection beam is off.

The object to be shielded is preferably a mask, since particles adhering to the mask are most detrimental to the quality of the projected image, but may also be a mirror or other element in the illumination or projection systems. Particles incident on, and possibly chemically reacting with, such elements may cause a loss in the reflectivity and therefore errors in the illumination dose received at the substrate.

By using electromagnetic fields rather than a physical barrier, the particle shield of the present invention performs its function without any attenuation of the projection beam.

The present invention also provides a device manufacturing method comprising the steps of:

providing a substrate which is at least partially covered by a layer of radiation sensitive material to said second object table;

providing a projection beam of radiation using a radiation system;

using patterning means to enclose the projection beam with a pattern in its cross section;

projecting the patterned beam of radiation onto a target portion of the layer of radiation sensitive material; characterized by the step of:

generating an electromagnetic field in the vicinity of an object to be shielded to deflect particles approaching said object to be shielded.

Although specific reference may be made in this text to the use of the apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid crystal display panels, thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "target portion", respectively.

In the present document, unless the context otherwise requires the terms "radiation" and "beam" are used to encompass all types of electromagnetic radiation, including ultraviolet radiation (*e.g.* with a wavelength of 365nm, 248nm, 193nm, 157nm or 126nm) and EUV (extreme ultraviolet radiation, *e.g.* having a wavelength in the range 5nm to 20nm), as well as particle beams, such as ion beams or electron beams.

The present invention and its attendant advantages will be described below with reference to exemplary embodiments and the accompanying schematic drawings, in which:

Figure 1 depicts a lithographic projection apparatus according to a first embodiment of the invention;

Figure 2 is a diagram of a particle shield in the first embodiment of the present invention;

Figure 3 is a diagram of a particle shield in a second embodiment of the present invention;

Figure 4 is a diagram showing the induced dipole moment in a neutral particle;

Figure 5 is a diagram of a particle shield in a third embodiment of the present invention;

Figure 6 is a diagram of a particle shield in a fourth embodiment of the present invention;

Figure 7 is a diagram of a particle shield in a fifth embodiment of the present invention;

Figure 8 is a diagram of a particle shield in a sixth embodiment of the present invention;

Figure 9 is a diagram of relevant parts of a lithographic apparatus incorporating particle shields according to a seventh embodiment of the present invention;

Figure 10 is a diagram of a particle shield in an eighth embodiment of the present invention;

Figure 11 is a diagram of a particle shield in a variant of the eighth embodiment of the present invention;

Figure 12 is a diagram of a particle trap in a ninth embodiment of the present invention;

Figure 13 is a diagram of a vacuum seal incorporating a particle shield according to a twelfth embodiment of the present invention; and

Figure 14 is a partial cross-sectional view of a mask storage box according to a thirteenth embodiment of the invention.

In the various drawings, like parts are indicated by like references.

Embodiment 1

Figure 1 schematically depicts a lithographic projection apparatus according to a particular embodiment of the invention. The apparatus comprises:

- a radiation system Ex, IL, for supplying a projection beam PB of radiation (*e.g.* EUV radiation), which in this particular case also comprises a radiation source LA;
- a first object table (mask table) MT provided with a mask holder for holding a mask MA (*e.g.* a reticle), and connected to first positioning means for accurately positioning the mask with respect to item PL;

- a second object table (substrate table) WT provided with a substrate holder for holding a substrate W (*e.g.* a resist coated silicon wafer), and connected to second positioning means for accurately positioning the substrate with respect to item PL;
- a projection system ("lens") PL (*e.g.* a mirror system) for imaging an irradiated portion of the mask MA onto a target portion C (*e.g.* comprising one or more dies) of the substrate W.

As here depicted, the apparatus is of a reflective type (*i.e.* has a reflective mask). However, in general, it may also be of a transmissive type, for example (with a transmissive mask). Alternatively, the apparatus may employ another kind of patterning means, such as a programmable mirror array of a type as referred to above.

The source LA (*e.g.* a discharge or laser produced plasma source) produces a beam of radiation. This beam is fed into an illumination system (illuminator) IL, either directly or after having traversed conditioning means, such as a beam expander Ex, for example. The illuminator IL may comprise adjusting means AM for setting the outer and/or inner radial extent (commonly referred to as σ-outer and σ-inner, respectively) of the intensity distribution in the beam. In addition, it will generally comprise various other components, such as an integrator IN and a condenser CO. In this way, the beam PB impinging on the mask MA has a desired intensity distribution in its cross-section.

It should be noted with regard to Figure 1 that the source LA may be within the housing of the lithographic projection apparatus (as is often the case when the source LA is a mercury lamp, for example), but that it may also be remote from the lithographic projection apparatus, the radiation beam which it produces being led into the apparatus (e.g. with the aid of suitable directing mirrors); this latter scenario is often the case when the source LA is an excimer laser. The current invention and Claims encompass both of these scenarios.

The beam PB subsequently intercepts the mask MA, which is held on a mask table MT. Having been selectively reflected by the mask MA, the beam PB passes through the lens PL, which focuses the beam PB onto a target portion C of the substrate W. With the aid of the second positioning means (and interferometric measuring means IF), the substrate table WT can be moved accurately, *e.g.* so as to position different target portions C in the path of the beam PB. Similarly, the first positioning means can be used to accurately position the mask MA with respect to the path of the beam PB, *e.g.* after mechanical retrieval of the mask MA from a mask library, or during a scan. In general, movement of the object tables MT, WT will be realized with the aid of a long-stroke module (course positioning) and a short-stroke module (fine positioning), which are not explicitly depicted in Figure 1. However, in the case of a wafer stepper (as opposed to a step-and-scan apparatus) the mask table MT may just be connected to a short stroke actuator, or may be fixed.

The depicted apparatus can be used in two different modes:

1. In step mode, the mask table MT is kept essentially stationary, and an entire mask image is projected in one go (*i.e.* a single "flash") onto a target portion C. The substrate table WT is then shifted in the x and/or y directions so that a different target portion C can be irradiated by the beam PB;

2. In scan mode, essentially the same scenario applies, except that a given target portion C is not exposed in a single "flash". Instead, the mask table MT is movable in a given direction (the so called "scan direction", *e.g.* the y direction) with a speed v, so that the projection beam PB is caused to scan over a mask image. Concurrently, the substrate table WT is simultaneously moved in the same or opposite direction at a speed $V = Mv$, in which M is the magnification of the lens PL (typically, $M = 1/4$ or $1/5$). In this manner, a relatively large target portion C can be exposed, without having to compromise on resolution.

Figure 2 shows an electrostatic particle shield 10 provided in the vicinity of mask MA. The particle shield 10 of the invention is attached to the mask holder or mask table MT, rather than the mask itself, as are conventional pellicles. It will be seen that the mask MA is reflective and disposed generally horizontally with the reflecting surface facing downward. The incident projection beam PBi is directed from the illumination system IL generally upwardly onto the mask MA and the reflected projection beam PBr is then reflected downwards to the projection system PL. As the operative surface of the mask faces downwards, gravity will tend to keep particles present in the apparatus away from the mask. However the powerful EUV projection beam provides energy to particles in its path which can enable them to overcome gravity. In particular, photons in the incident projection beam PBi colliding with particles will impart a generally upward momentum. Thus, contaminant particles can be driven towards the mask MA where they will cause undesirable contamination. Moving parts of the apparatus can also both create contaminant particles and provide transport energy to overcome gravity.

To prevent this, the electrostatic particle shield 10 comprises two capacitor like plates 11, 12 placed perpendicular to the mask on either side of it. The plates 11, 12 are oppositely charged so as to establish an electric field E between them. Assuming that the area of the plates 11, 12 is substantially greater than their separation, d, the electric field, E, is given by:

$$E = \frac{V}{d} \qquad (3)$$

where V is the voltage across the capacitor. In an embodiment of the present invention, the separation, d, may be about 300mm, approximately twice the width of a mask, and the potential difference between plates 11, 12 may be about 10kV. This gives an electric field of 33kV/m.

The force exerted on a charged particle in the electric field between capacitor plates 11, 12, is equal to the product of the charge on the particle and the electric field strength, E. In an operating lithographic apparatus using EUV exposure radiation it can be assumed that any particles entering the projection beam will become rapidly ionized. The energy of an EUV photon is 92eV compared to an ionization energy of the order of only a few eVs. A particle of 20nm diameter in a projection beam having a typical power density of $8kW/m^2$ will be impacted by about 1.7×10^5 photons per second and will thus very likely be multiply ionized. For a singly ionized particle, the worst case, the force exerted on the particle will be about 5.3×10^{-15} N. It can be shown that this force is sufficient to prevent such particles reaching the mask. The time, t, taken for a particle to move from one capacitor plate to the other, the worst case situation, is given by:

$$t = \sqrt{\frac{2dm}{F}} \qquad (4)$$

where m is the mass of the particle and F the electrical force. Table 1 below gives the transit time for various different sizes of particle, assuming a spherical particle having a density ρ equal to $2{,}000kg/m^3$.

Particle Size	Time
20nm	0.1ms
100nm	11ms
500nm	0.11s
1μm	0.35s

In the worst case, a particle ejected from a metal part in the apparatus, e.g. following a collision, could be moving at maximum at the speed of sound in the metal, e.g. about 5,000m/s. A particle of 20nm diameter moving at this speed through the capacitor will be deflected if the height, h, of the capacitor plates 11, 12 is about 500mm. This is the case even if the particle is only minimally charged. It should also be noted that, due to their substantially higher charge to

mass ratios, any ions or charged molecules would be very quickly deflected by the electrostatic particle shield 10.

In a variant of the first embodiment, an alternating voltage is provided between electrodes 11 and 12 to generate a plasma that is confined between the electrodes and serves as a barrier to contaminant particles approaching the mask MA. Neutral particles approaching the plasma will rapidly become ionized and trapped in the plasma. The plasma may be formed in a atmosphere of an inert gas, e.g. Argon, at a pressure of the order of 1 mbar. The alternating voltage may be such as to establish a field strength of about 100 to 500 V/cm and may have a frequency of about 1 to 10 MHz.

Embodiment 2

A second embodiment of the present invention, which may be the same as the first embodiment save as described below, includes an electrostatic particle shield 20 making use of a non-uniform electric field, which may prove more efficient.

The electrostatic particle shield 20 of the second embodiment of the invention is shown in Figure 3. An elongate charged member 21 is placed perpendicular to and to one side of the mask MA, adjacent the volume traversed by the incident and reflected projection beams PBi, PBr. A single charged member, as opposed to a pair of charged plated forming a capacitor, forms a non-uniform electric field, which induces a dipole in neutral molecules and particles and then exerts a force on the dipole. A non-uniform electric field will also exert a force on polar molecules and so will capture these as well as neutral molecules or particles in which a dipole moment is induced. The force exerted on a dipole is given by:

$$\bar{F} = (\bar{p}.\bar{\nabla})\bar{E} \qquad (5)$$

where p is the induced dipole moment of the particle. The elongate charged member 21 can be approximated as a cylinder with a charge per unit length of the cylinder of μCoulomb/m. This will induce an electric field given by:

$$E(\bar{r}) = \frac{\mu}{2\pi\varepsilon_0 r} \qquad (6)$$

where $\bar{r}$ is a position vector in an arbitrary coordinate system, r is the distance to the center of the cylinder, and ε_0 is the dielectric constant in vacuum. The electric field inside a sphere with dielectric constant ε is given by:

$$E_{particle}(\bar{r})=\frac{3}{\varepsilon+2}E(\bar{r}), \tag{7}$$

whilst the electric field which is induced by displaced charges inside the particle is given by:

$$E_{induced}(\bar{r})=-\frac{\varepsilon-1}{\varepsilon+2}E(\bar{r}). \tag{8}$$

The polarization P is defined as the dipole moment per unit volume and given by:

$$P=\varepsilon_0(\varepsilon-1)E_{particle}=\frac{\varepsilon-1}{\varepsilon+2}3\varepsilon_0 E(r), \tag{9}$$

for a particle at a distance r from the center of the charged cylinder so that the particle having a radius r_p can be replaced by a dipole with a moment, p, given by:

$$p=\frac{\varepsilon-1}{\varepsilon+2}4\pi\varepsilon_0 r_p^3 E(r). \tag{10}$$

The particle can thus be regarded as charges +Q, -Q separated by twice the radius r_p of the particle, as shown in Figure 4. The magnitude of the charges Q is given by:

$$Q=\frac{\varepsilon-1}{\varepsilon+2}2\pi\varepsilon_0 r_p^2 E(r)=\frac{\varepsilon-1}{\varepsilon+2}\frac{r_p^2\mu}{r}. \tag{11}$$

From this, the force on the dipole can be expressed as:

$$F=QE(r-r_p)-QE(r+r_p)=\frac{Q\mu}{2\pi\varepsilon_0(r-r_p)}-\frac{Q\mu}{2\pi\varepsilon_0(r+r_p)} \tag{12}$$

which can be approximated, when the particle radius is small compared to the distance from the elongate charge member 21, as:

$$F \cong \frac{Q\mu}{2\pi\varepsilon_0 r}\cdot\frac{2r_p}{r} = \frac{Q\mu r_p}{\pi\varepsilon_0 r^2} = \frac{\varepsilon-1}{\varepsilon+2}\cdot\frac{\mu^2 r_p^3}{\pi\varepsilon_0 r^3}. \qquad (13)$$

Because this force is dependent on the cube of the particle radius, the acceleration experienced by particles is independent of size. For a particle of density, ρ, equal to 2,000kg/m^3 and a charge density, μ, of 10^{-7}Coulomb/m, the time to travel over a distance of about 150mm, the size of a mask, for different dielectric constants, ε, is given in Table 2 below:

ε	Time (s)
2	224
3	177
5	158
∞ (metal particles)	112

Although it does take a significant time for the particles to reach the charged member 21, the non-uniform field will effectively capture neutral particles in the apparatus since the non-uniform field can be arranged to extend for a distance several times the mask width in front of the mask, allowing plenty of time for the particles to be deflected.

Embodiment 3

A third embodiment of the present invention, which may be the same as the first or second embodiment save as described below, employs an optical particle shield which creates an optical breeze to deflect contaminant particles.

The third embodiment is shown in Figure 5 and comprises radiation source 31 which emits high intensity shielding beams 32 of electromagnetic radiation parallel to the mask MA and across the space in front of it. The radiation source 31 can be any suitable source, or array of sources, with appropriate collimating and/or directing means to direct the beam across the required space whilst minimizing generation of stray light outside the desired area. A beam absorber 33 may be placed the other side of the space in front of the mask MA to absorb the

shielding radiation and prevent reflections. The photons of the shielding beams 32 carry momentum m_r which will be transferred to any particle which absorbs photons from the beams 32. The wavelength of the light in the particle shield 30 is therefore chosen to be absorbed by all particles expected. The wavelength may also be chosen as one to which the resist used is not sensitive so that any stray light, which does reach the substrate, does not expose the resist.

The pressure exerted by a radiation beam of intensity I per m^2 is given by:

$$P_{BEAM} = \frac{I}{c} \tag{14}$$

where c is the velocity of light (3×10^8m/s). The acceleration of a spherical particle with radius r_p and density ρ is given by:

$$a_{breeze} = \frac{3I}{4 c r_p \rho} \tag{15}$$

which is constant with time so that the time required to travel over a distance d is given by:

$$t = \sqrt{\frac{2d}{a_{breeze}}} = \sqrt{\frac{8 d c r_p \rho}{3I}} \tag{16}$$

The time taken for particles of various sizes to travel over a distance of 150mm, the approximate size of a mask, are given in Table 3 below, assuming a particle density, ρ, of 2,000kg/m^3 and an intensity of 8kW/m^2.

Particle Size (nm)	Time (s)
10	0.4
25	0.6
50	0.9
100	1.8

Again, if the optical particle shield 30 is arranged to extend over a substantial distance in front of the mask MA, a significant deflection can be achieved. In particular, the optical particle shield can be arranged to have a similar radiation intensity to the projection beam PB so that the deflection

force exerted by the optical shield is comparable to the force exerted by the projection beam tending to lift the particles towards the mask MA.

Embodiment 4

In a fourth embodiment, which may be the same as the first to third embodiments save as described below, additional ionizing radiation is provided in front of the element to be protected which is itself charged to repel ions approaching it.

Figure 6 shows ionizing radiation source 41, which directs a transverse beam 42 of ionizing radiation across the region in front of the element to be protected, in this case mask MA. The beam 42 has a thickness, t, perpendicular to the functional surface of the mask MA which is sufficiently large to ensure ionization, preferably multiple ionization, of most or all atoms approaching the mask MA. The wavelength of the radiation should be short (energetic) enough to ensure ionization of all atoms expected, and thus should preferably be shorter than 200nm (6.2eV). For example, an He discharge lamp emitting 59nm radiation (21eV) is suitable. Such sources are generally pulsed and in that case should have a repetition rate fast enough to irradiate all atoms passing through the protective region. For example, a repetition rate of 4kHz may be used with a beam width of 100mm. A gas molecule moving at $400ms^{-1}$, a typical speed at room temperature, will traverse the shield in a minimum of 0.25ms and thus will be illuminated by at least one pulse.

Embodiment 5

The fifth embodiment, shown in Figure 7, is a variant of the fourth embodiment. In the fifth embodiment, collector plates 43, which are negatively charged relative to the mask MA, are added to increase the shielding effect. The collector plates 43 are situated on the other side of the protective beam 42 than the mask MA and serve to attract the positively charged ions repelled by the relatively positive mask MA.

Embodiment 6

The sixth embodiment shown in Figure 8, is a variant of the fifth embodiment but relies on the projection beam PB to ionize any contaminants approaching the mask MA. In this embodiment the collector shield 43 can be positioned closer to the mask and the path of the projection beam PB.

Embodiment 7

Figure 9 shows part of the illumination system IL, the mask MA and the projection system PL of a lithographic apparatus according to a seventh embodiment of the present invention, which is the same as the first embodiment save as described below.

In the seventh embodiment, a mirror box 40 partially encloses mirrors 42 forming the projection system PL and mirrors 43 forming at least part of the illumination system IL. The mirror box 40 may also be referred to as the projection optics box. According to the invention, the mirror box 40 is provided with electrodes 41 on most of its surfaces, internal and external. The electrodes 41 may be formed as conductive coatings on the surfaces of the mirror box 40. In use of the apparatus, the electrodes 41 are connected to a power supply 44 (e.g. 5 Volts) so that they become charged either positively or negatively. The mask MA is preferably earthed.

When the apparatus is in use, the mirror box 40 and the mirrors or other optical elements enclosed within it will be under vacuum (in some cases the mirror box 40 may form part of the vacuum chamber wall) and the charged electrodes 41 serve to attract particulates remaining in the vacuum system. Once the particulates have been attracted to and collide with the electrodes 41 they will tend to stick thereto and thus the amount of particulate contamination of the vacuum is reduced.

Preferably, as much free surface area as possible is provided with electrodes to maximize capturing of particulates in the vacuum. As well as the mirror box 40, capture electrodes can be provided on any suitable surface of the vacuum system, for example the rear surfaces of mirrors and other reflective optical elements. A preferable minimum is to provide all suitable surfaces facing and close to the mask with conductive electrodes. In the event that the mirror box 40 is conductive and any sensitive components attached to it can be insulated, it would be possible to charge the mirror box 40 itself to form the particle trap electrodes.

Embodiment 8

An eighth embodiment of the invention provides a particle shield or trap which is shown in Figure 10 and can be used in a lithographic apparatus such as described with relation to the first embodiment or in a mask handling or transport apparatus, or a storage box.

The particle shield 50 of the eighth embodiment comprises a one- or two-dimensional grid or array of electrodes, 51, 52 which is disposed in proximity to the pattern side P of the mask MA. When the particle shield 50 is used in a mask handling apparatus or mask storage box it can

cover the entire surface area of the pattern P. In a lithographic apparatus, the particle shield is either moved out of the way for exposures or provided with a slit corresponding to the illuminated area. To prevent small particles reaching the pattern side of the mask MA, adjacent ones of the electrodes 51, 52 are charged to opposite polarities by power source 53. This establishes electrostatic fields between the adjacent electrodes, which attract positive and negatively charged particles to the oppositely charged electrodes. It should be noted that the electrodes need not be continuously connected to the power supply. If they are well insulated and kept in a vacuum, sufficient charge may be retained by the electrodes to protect the mask MA for a period of time after the power supply has been disconnected.

Figure 11 shows a modified particle shield according to the eighth embodiment. In the particle shield 50a the electrodes 51a, 52a are provided with peaks or ridges so as to enhance field gradients in their vicinity and improve the particle trapping effect.

Embodiment 9

In the ninth embodiment which, as with the eighth embodiment can be applied in a lithographic projection apparatus, a mask handling apparatus or a mask storage box, physical particle traps are provided. These are shown in Figure 12.

The physical particle trap is formed in a recess 62 in a surface of a protective plate 60. Within the recess 62 a plurality of projections 61 are provided. The projections 61 have barbs, in a tree like structure, so that particles entering the recess are hindered by the barbs from escaping and will tend to be captured. The capturing effect can be enhanced by charging the projections 61 (as described in embodiment 8) and/or the base of the recess 62. Preferably, the plate 62 is maintained cold so that particles colliding with it will tend to lose kinetic energy, further enhancing the trapping effect. The recess 62 and projections 61 should be made small and can be manufactured using etching techniques.

Embodiment 10

In a tenth embodiment, which is not illustrated, particles are prevented from colliding with and sticking to the mask MA in a lithographic apparatus, a mask handling apparatus or a mask storage box by providing a temperature difference between the mask and its surroundings.

The temperature difference can be provided by providing a heater, e.g. a lamp, to heat the mask and/or by providing a cold plate, cooled by a suitable cooler, in the vicinity of the pattern surface of the mask MA. The presence of a cold surface near the mask reduces particle

adherence to the mask because particles colliding with the cold surface will tend to lose kinetic energy and hence are more likely to stick to the cold surface. Heating the mask to a temperature higher than its surrounding causes a continuous thermophoretic effect.

Embodiment 11

In an eleventh embodiment, also not illustrated, a plate matching the mask in area may be positioned underneath its patterned side except during exposure periods. The shielding plate may be spaced a distance in the range of from 5mm to 20mm from the mask and may be constructed as a particle shield according to any or all of the eighth, ninth and tenth embodiments.

Embodiment 12

A twelfth embodiment of the invention provides a vacuum seal shown in Figure 13, which may be used in a vacuum chamber of a lithographic apparatus or a mask handling apparatus.

In the twelfth embodiment two wall parts 71, 72 partially overlap and are sealed together by a mechanical seal 73. The walls 71, 72 separate a vacuum chamber V from ambient pressure A. On the vacuum side of the mechanical seal 73, two electrodes 74, 75 are provided, one on wall part 71 and one on wall part 72. The electrodes 74, 75 are connected to power supply 76 so as to be charged to opposite polarities. These electrodes then serve to trap any charged particles that may be generated by mechanical seal 73. Further, any one of the solutions of embodiments 9 and 10 may be provided near seal 73 on the vacuum side to trap particles from seal 73.

Embodiment 13

A thirteenth embodiment of the invention provides a mask storage box in which mask may be stored for extended periods of time.

A mask storage box 80, shown in part in Figure 14, comprises a main housing 81 and a housing bottom 82 which form an enclosed chamber in which mask MA may be stored. The mask MA is held in place by appropriate clamping means (not shown). The enclosed chamber may be under vacuum or filled with a contaminant-free inert gas. In ether case, the housing is closed by seal 83. Where the enclosed chamber is under vacuum, the seal 83 may incorporate electrodes to trap particles as described in the twelfth embodiment.

Also within the enclosed chamber, a particle shield device 84 is provided. The particle shield device 84 serves to trap particles that may be present in the enclosed chamber or otherwise prevent them reaching the mask MA, particularly the patterned surface thereof, and may be constructed as described above in relation to any or the first to tenth embodiments. Where the particle shield 84 requires power, this may be provided from a power source included in the mask storage box 80 or an external power source. Preferably, the particle shield is arranged to be powered from an external source during long-term storage but is also provided with a, preferably rechargeable, internal power source to maintain the particle shield 84 operational during transportation.

Whilst we have described above specific embodiments of the invention it will be appreciated that the invention may be practiced otherwise than described. The description is not intended to limit the invention. In particular, it will be appreciated that the particle shields of the different embodiments may be combined so that a particle shield according to the invention may make use of any one or more of: a uniform electric field, a non-uniform electric field, an optical breeze, ionizing radiation and charging of the object to be shielded. The invention can be used in lithography apparatus using any form of projection beam, especially but not exclusively, 193nm, 157nm or EUV.

CLAIMS

1. A lithographic projection apparatus comprising:

a radiation system for supplying a projection beam of radiation;

a support structure for supporting patterning means, the patterning means serving to pattern the projection beam according to a devised pattern;

a substrate table for holding a substrate; and

a projection system for projecting the patterned beam onto a target portion of the substrate; characterized by

particle shield means for generating an electromagnetic field to deflect particles approaching an object to be shielded.

2. Apparatus according to Claim 1 wherein said particle shield means is adapted to generate a non-uniform electric field in the vicinity of said object to be shielded.

3. Apparatus according to Claim 2 wherein said particle shield means comprises an elongate charged member.

4. Apparatus according to Claim 1 wherein said particle shield means is adapted to generate a substantially uniform electric field in the vicinity of said object to be shielded.

5. Apparatus according to Claim 4 wherein said particle shield means comprises a pair of conductive plates arranged substantially parallel to each other on either side of a region adjacent said object to be shielded and means for establishing a potential difference between said pair of conductive plates.

6. Apparatus according to Claim 1 wherein said particle shield means comprises a grid or an array of electrodes and means for charging adjacent ones of said electrodes to opposite polarities.

7. Apparatus according to Claim 6 wherein said electrodes are provided with peaks or ridges to enhance field gradients in the vicinity thereof.

8. Apparatus according to Claim 1 wherein said particle shield means comprising an electrostatic getterer plate provided in a vacuum chamber in which said object to be shielded is located and means for charging said electrostatic getterer plate to a potential at least 5V greater of less than said object to be shielded.

9. Apparatus according to Claim 1 wherein said electrostatic getterer plate comprises at least one electrode mounted on an enclosure of said projection system.

10. Apparatus according to Claim 1 wherein said particle shield means includes at least one particle trap, said particle trap comprising a recess in a surface, said recess being shaped so that it is easier for a particle to enter said recess than to exit said recess.

11. Apparatus according to any one of the preceding Claims wherein said particle shield means comprises a radiation source arranged to generate a beam of radiation in the vicinity of said object to be shielded.

12. Apparatus according to Claim 11 wherein said radiation source is adapted to generate an electromagnetic beam effective as an optical breeze to deflect particles by momentum transfer.

13. Apparatus according to Claim 11 or 12 wherein said radiation source is adapted to generate a beam of radiation capable of ionizing particles approaching said object to be shielded.

14. Apparatus according to Claim 11, 12 or 13 wherein said radiation source is adapted to direct said beam of radiation in a direction substantially parallel to said object to be shielded.

15. Apparatus according to any one of the preceding Claims wherein said particle shield means comprises means for charging said object to be shielded to a positive potential relative to its surroundings.

16. Apparatus according to any one of the preceding Claims wherein said particle shield means comprises collector plates positioned near said object to be shielded and means for charging said collector plates to a negative potential relative to said object to be shielded.

17. Apparatus according to any one of the preceding Claims wherein said support structure comprises a mask table for holding a mask.

18. Apparatus according to Claim 17 wherein said object to be shielded is a mask held on said mask table.

19. Apparatus according to Claim 18 wherein said particle shield means is mounted to said mask table.

20. Apparatus according to any one of Claims 1 to 17, wherein said object to be shielded is a mirror or other element comprised in the illumination or projection system.

21. Apparatus according to Claim 17 further comprising a mask handling part for transferring said mask to said mask table, and wherein said mask handling part comprises said particle shield means for shielding said mask.

22. Apparatus according to any one of the preceding Claims further comprising a substrate handling part for transferring said substrate to said substrate table, and wherein said substrate handling part comprises said particle shield means for shielding said substrate.

23. Apparatus according to any one of the preceding Claims wherein said projection beam comprises ultraviolet radiation having a wavelength less than about 200nm.

24. Apparatus according to any one of Claims 1 to 22 wherein said projection beam comprises extreme ultraviolet radiation, e.g. having a wavelength in the range of from 8nm to 20nm, especially 9nm to 16nm.

25. A device manufacturing method comprising the steps of:

providing a substrate which is at least partially covered by a layer of radiation sensitive material to said second object table;

providing a projection beam of radiation using a radiation system;

using patterning means to enclose the projection beam with a pattern in its cross section;

projecting the patterned beam of radiation onto a target portion of the layer of radiation sensitive material; characterized by the step of:

generating an electromagnetic field in the vicinity of an object to be shielded to deflect particles approaching said object to be shielded.

26. A device manufactured in accordance with the method of Claim 25.

27. A mask handling device comprising:

a chamber for enclosing a mask during handling, transportation or storage thereof; and

a particle shield for preventing or reducing the contamination of at least the patterned surface of said mask by particles.

28. A mask handling device according to claim 27 wherein said particle shield comprises particle shield means for generating an electromagnetic field to deflect particles approaching at least the patterned surface of said mask.

29. A mask handling device according to Claim 28 wherein said particle shield means comprises a grid or array of electrodes and means for charging adjacent ones of said electrodes to opposite polarities.

30. A mask handling device according to Claim 29 wherein said electrodes are provided with peaks or ridges to enhance field gradients in the vicinity thereof.

31. A mask handling device according to any one of Claims 27 to 30 wherein said particle shield comprises a heater for maintaining said mask at a temperature greater than its surroundings.

32. A mask handling device according to any one of Claims 27 to 31 wherein said particle shield comprises a plate disposed proximate said mask and a cooler for maintaining said plate at a temperature less than the temperature of said mask.

33. A mask handling device according to any one of claims 27 to 31 wherein said device is a mask storage box.

34. A vacuum seal for use in a mask handling apparatus or lithographic apparatus, the seal comprising a seal member positioned between a first wall part and a second wall part; at least one electrode positioned on the vacuum side of said seal proximate said seal member; and a power supply for charging said electrode to have a potential difference relative to at least one object contained on the vacuum side of said seal.

ABSTRACT

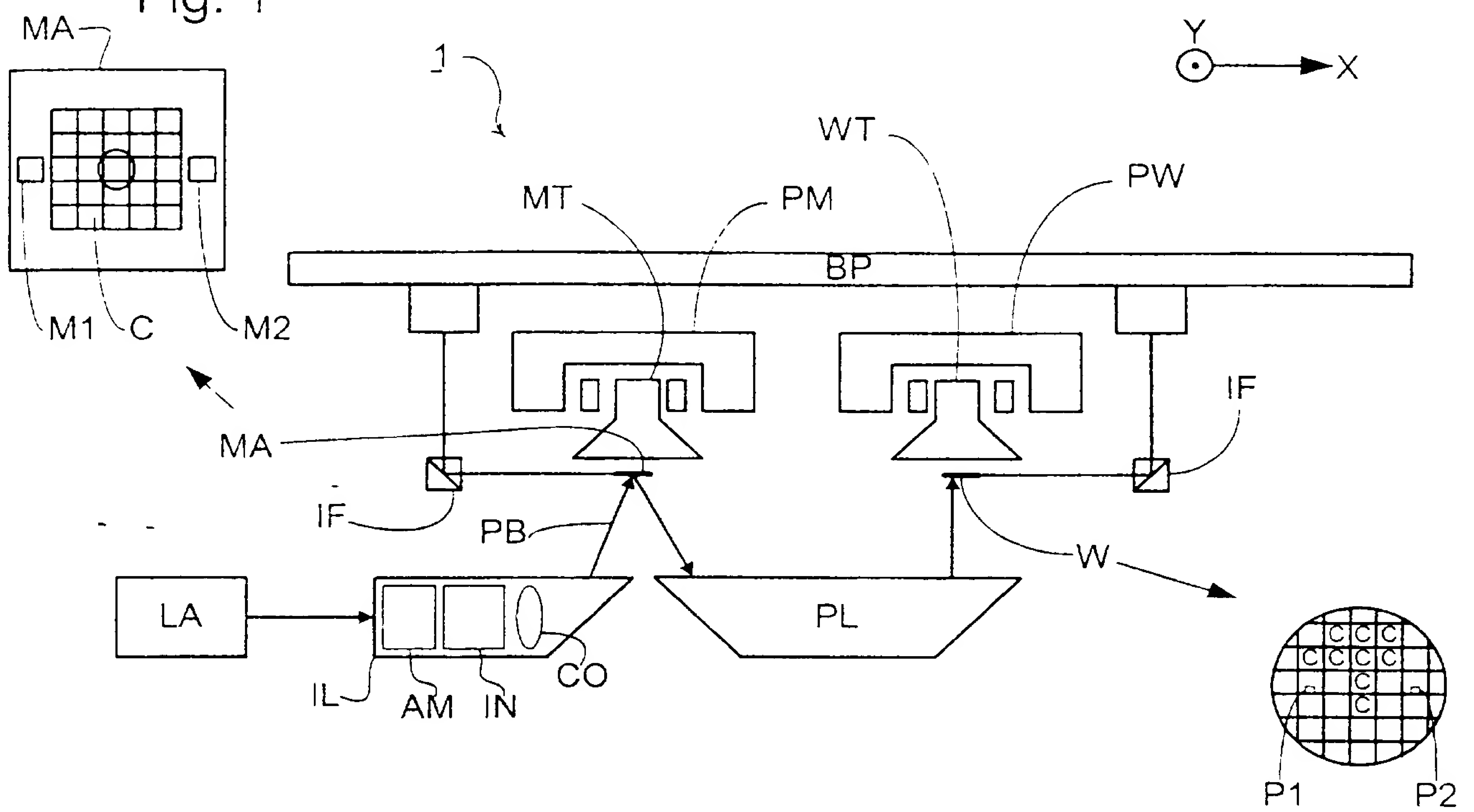
PARTICLE SHIELD, MASK HANDLING APPARATUS, LITHOGRAPHIC PROJECTION APPARATUS, DEVICE MANUFACTURING METHOD AND DEVICE MANUFACTURED THEREBY

In a lithographic projection apparatus, an object such as a mask is shielded from stray particles by a particle shield using electromagnetic fields. The fields may be a uniform electric field, a non-uniform electric field or an optical breeze. The particle shield means are fixed to the mask holder rather than the mask.

Figure 2

1/5

Fig. 1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C
M2
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Y
X
WT
PW
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PM
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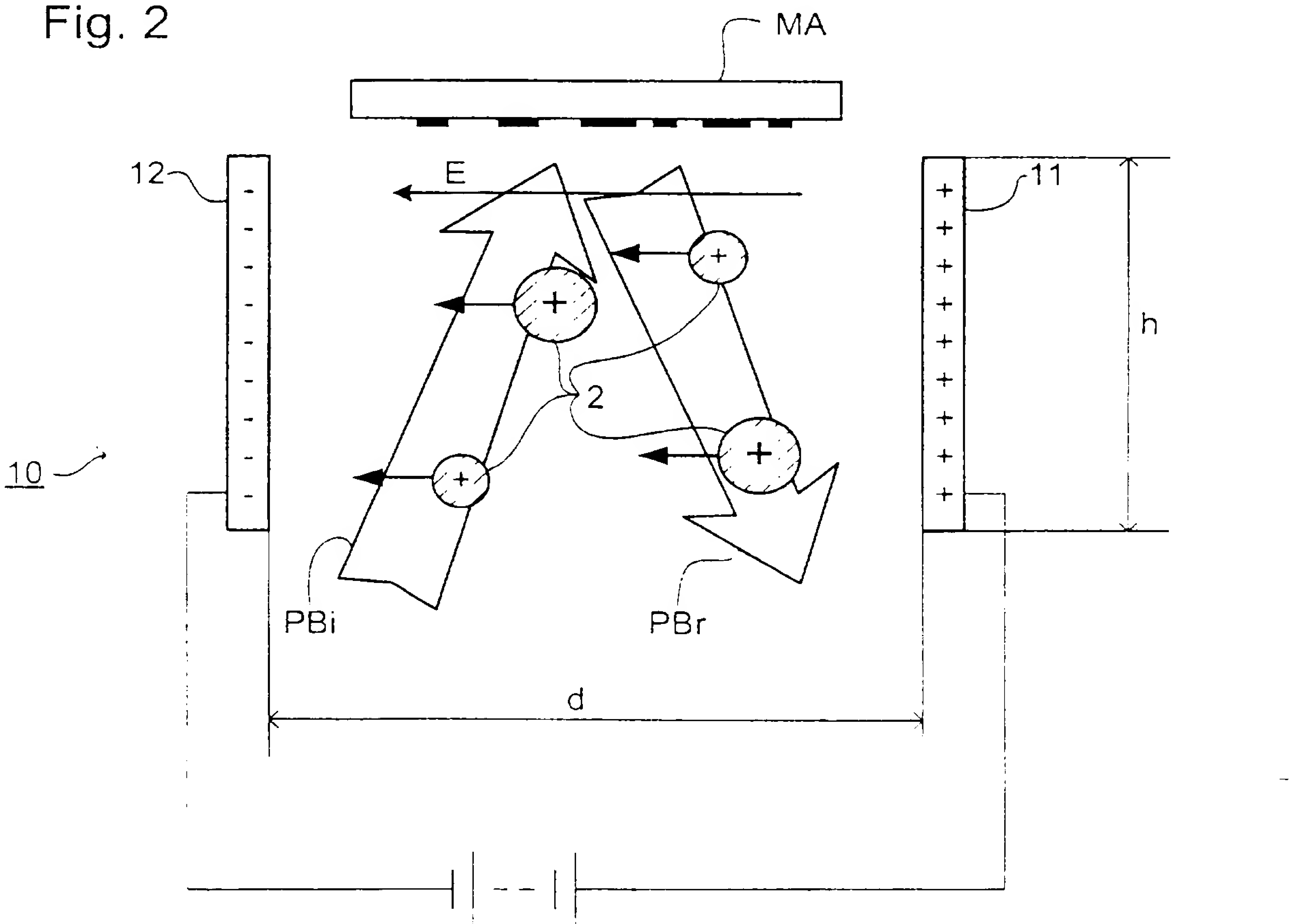
Fig. 2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12
E
11
h
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PBi
PBr
d

Fig. 3

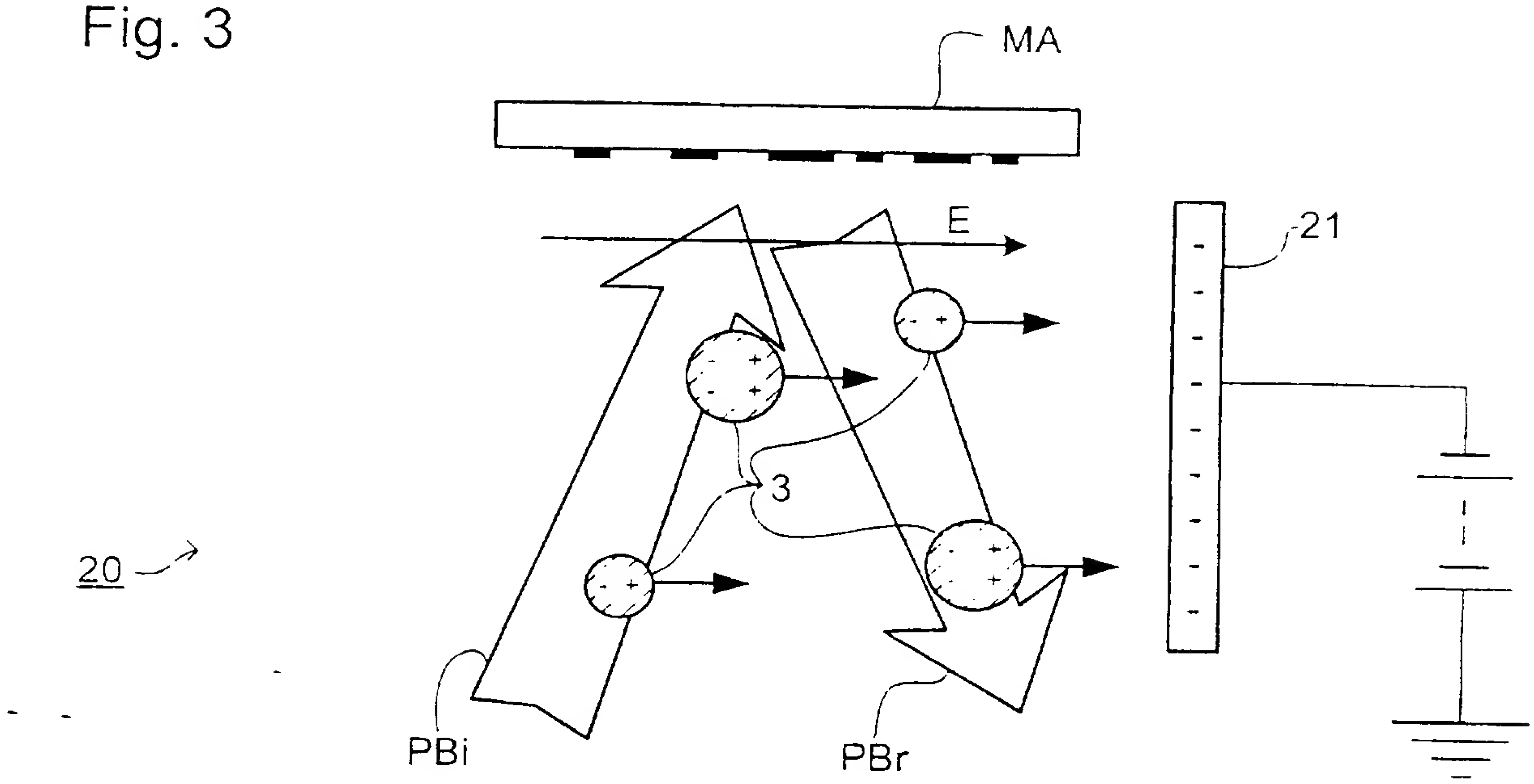

Fig. 4

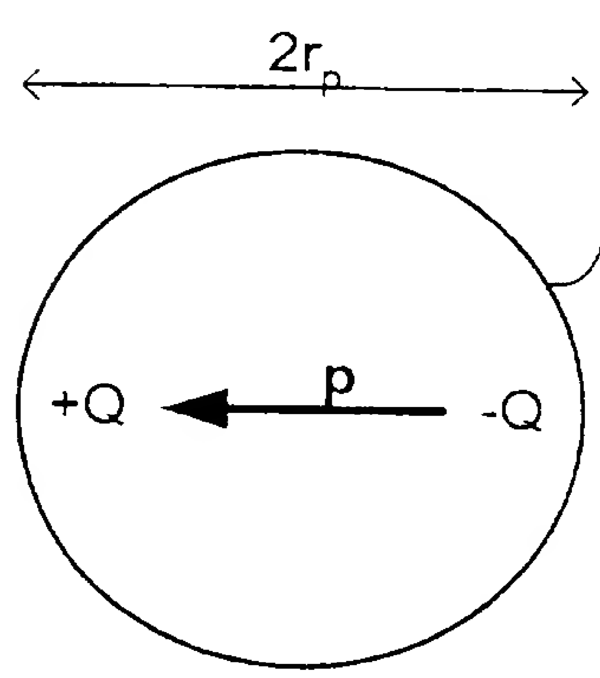

Fig. 5

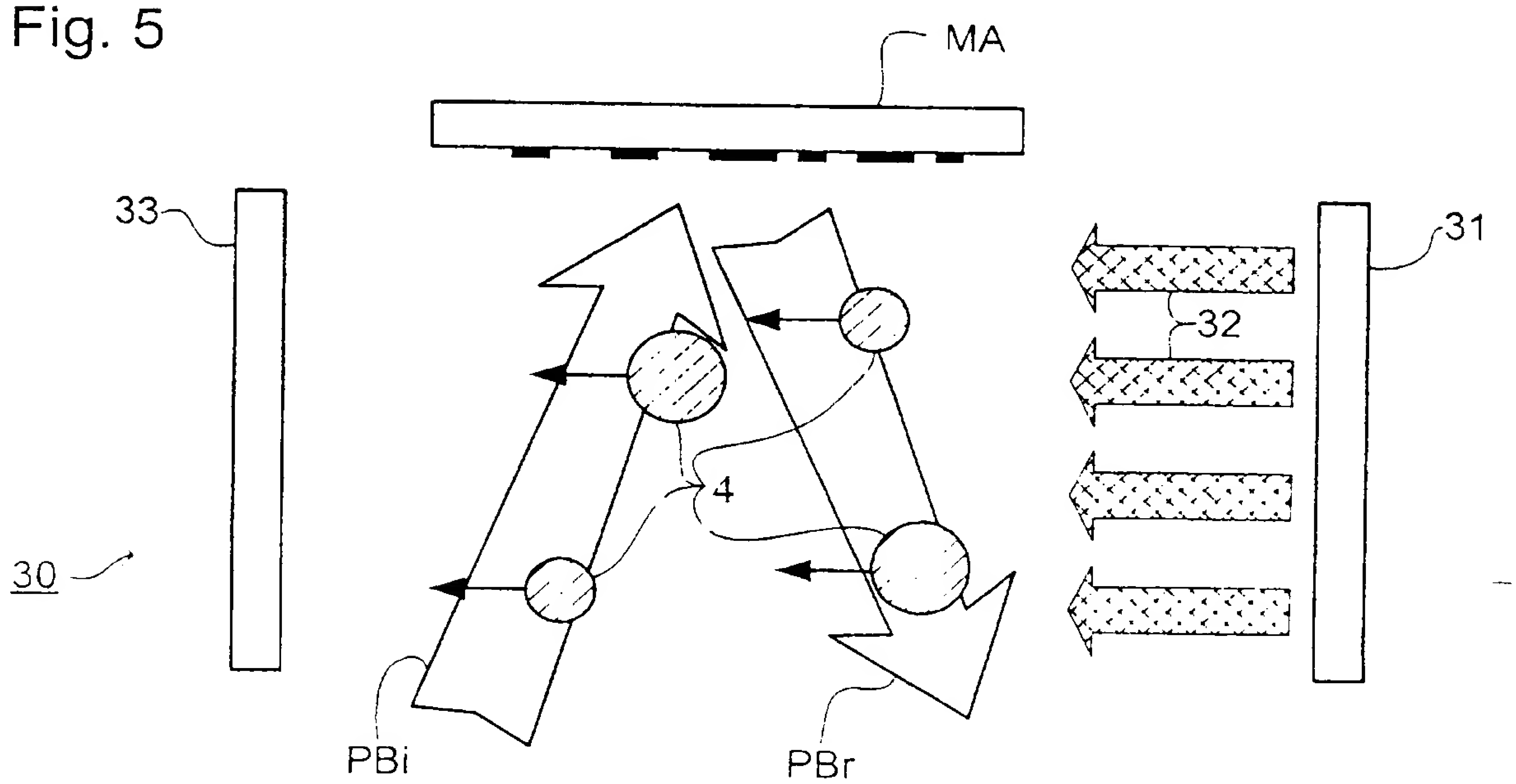

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Fig. 6

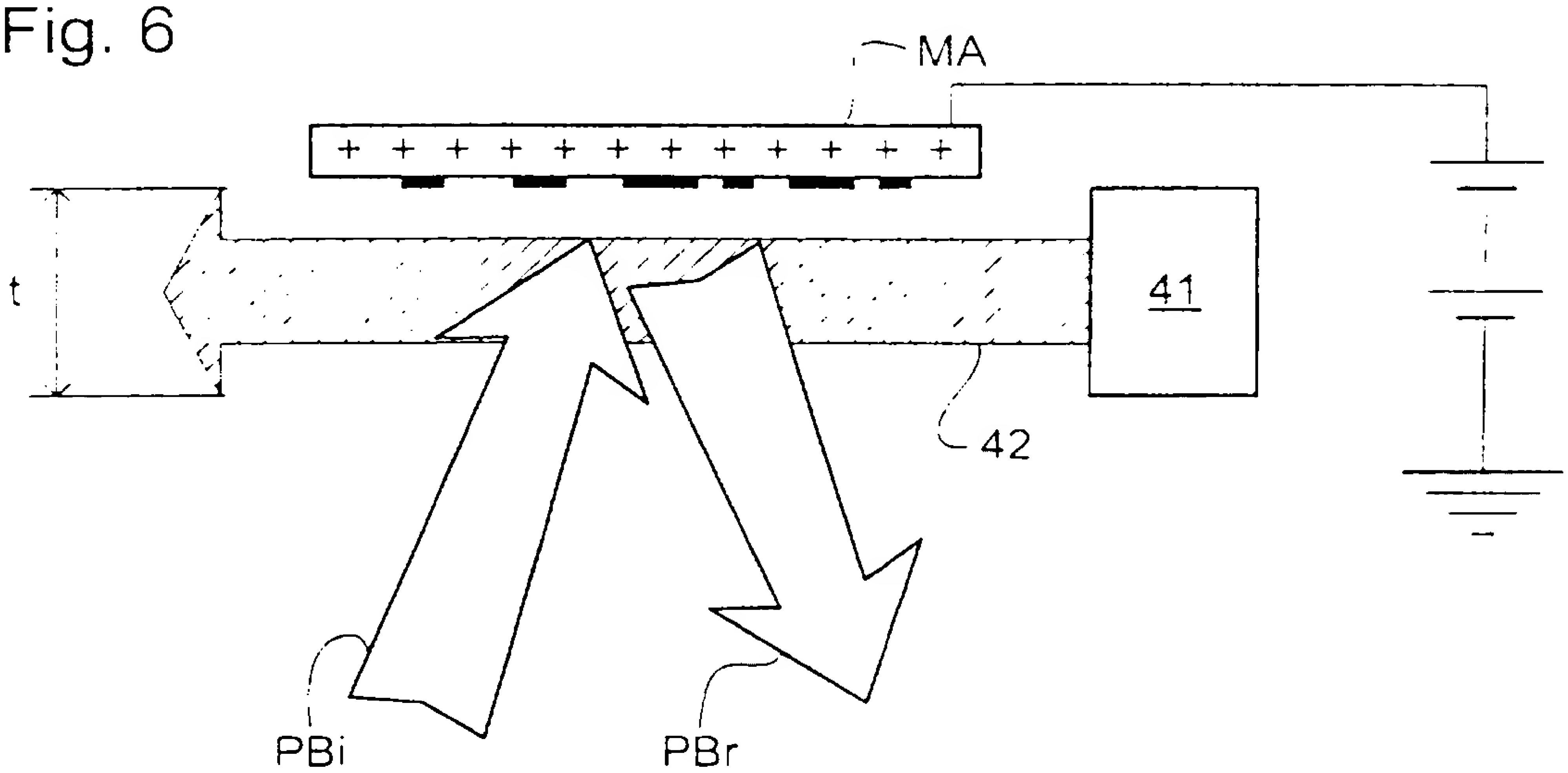

Fig. 7

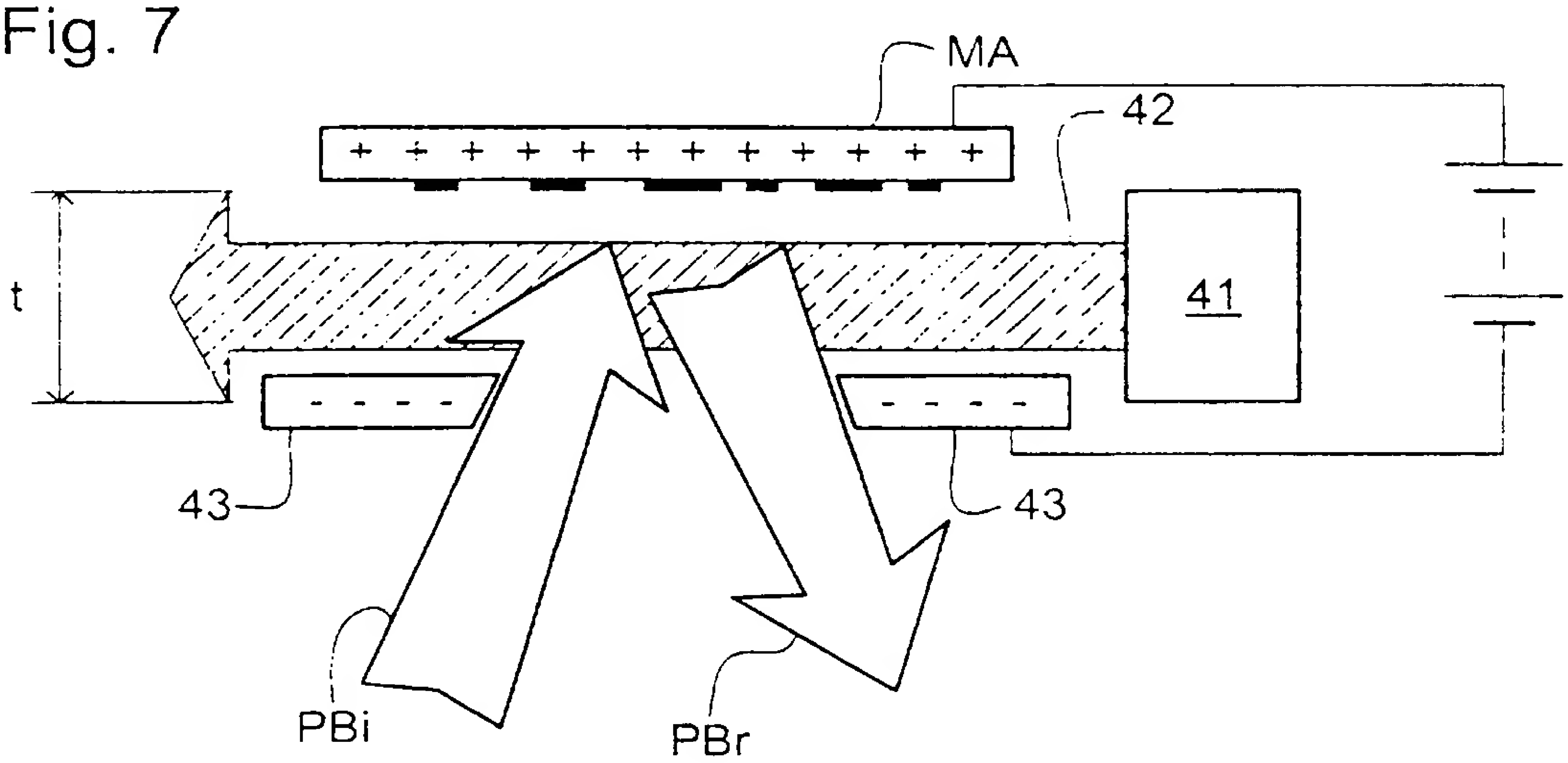

Fig. 8

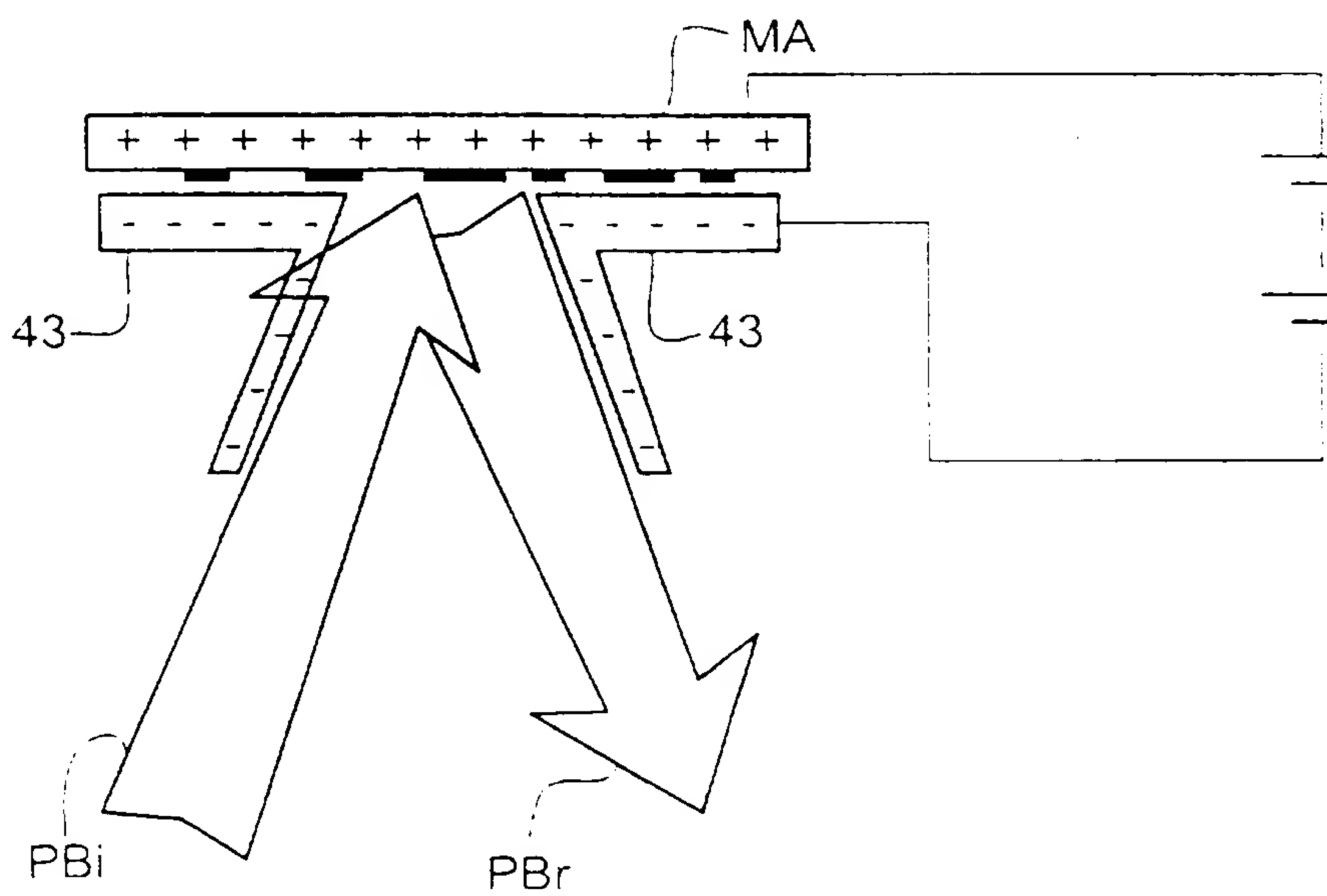

Fig. 9

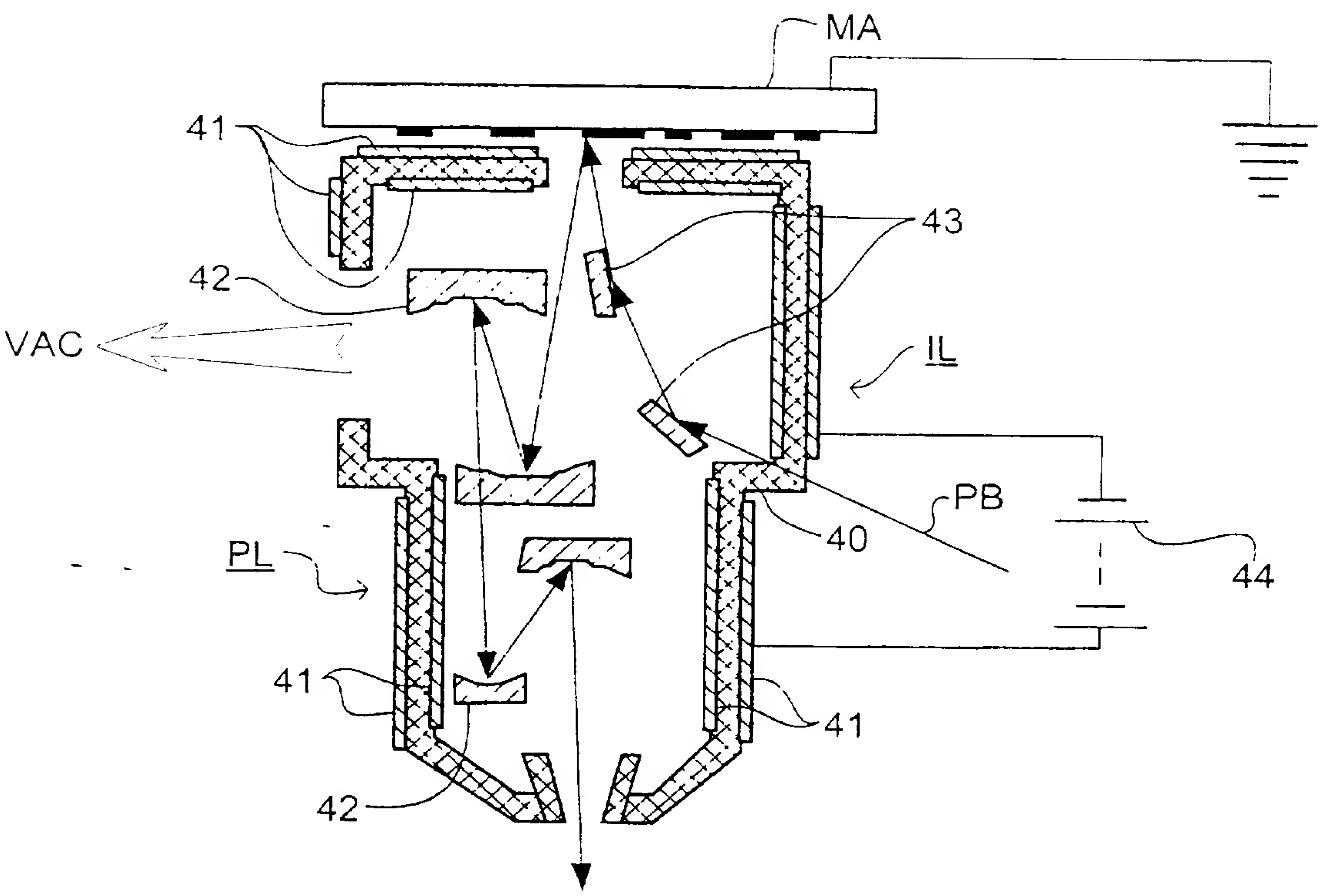

Fig. 10

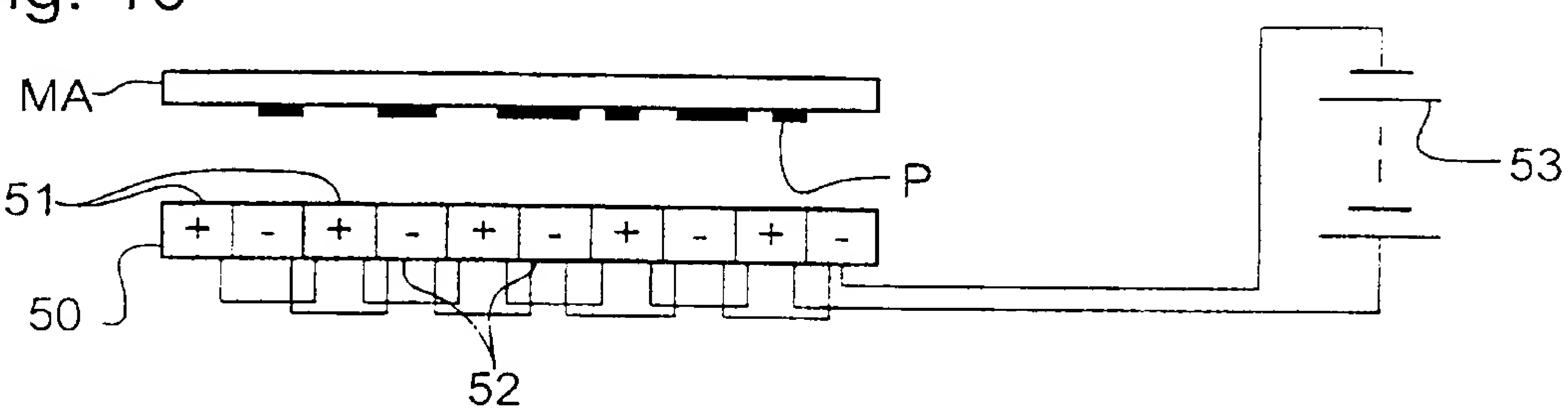

Fig. 11

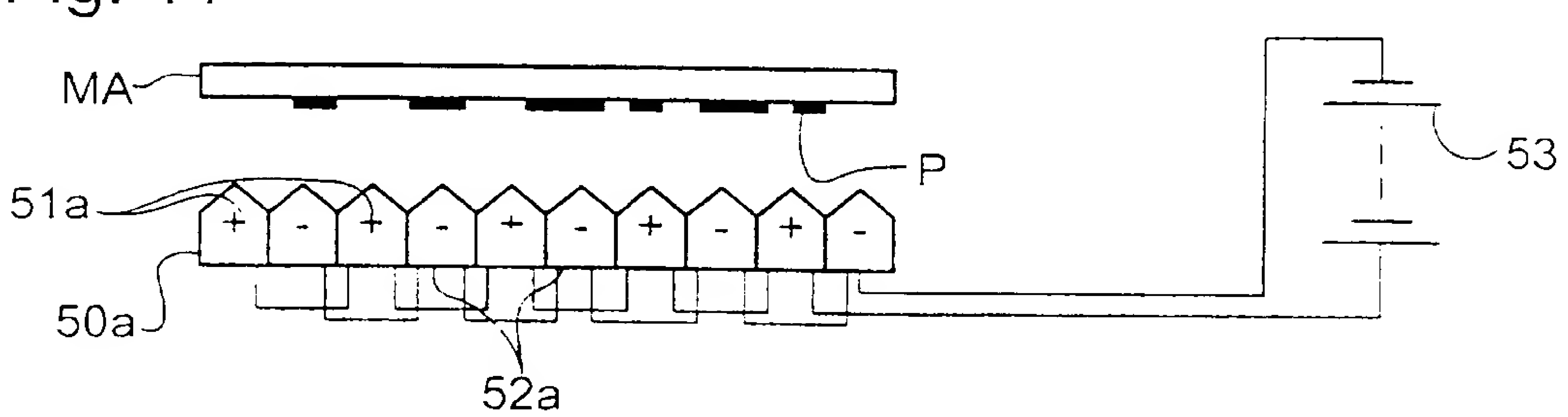

Fig. 12

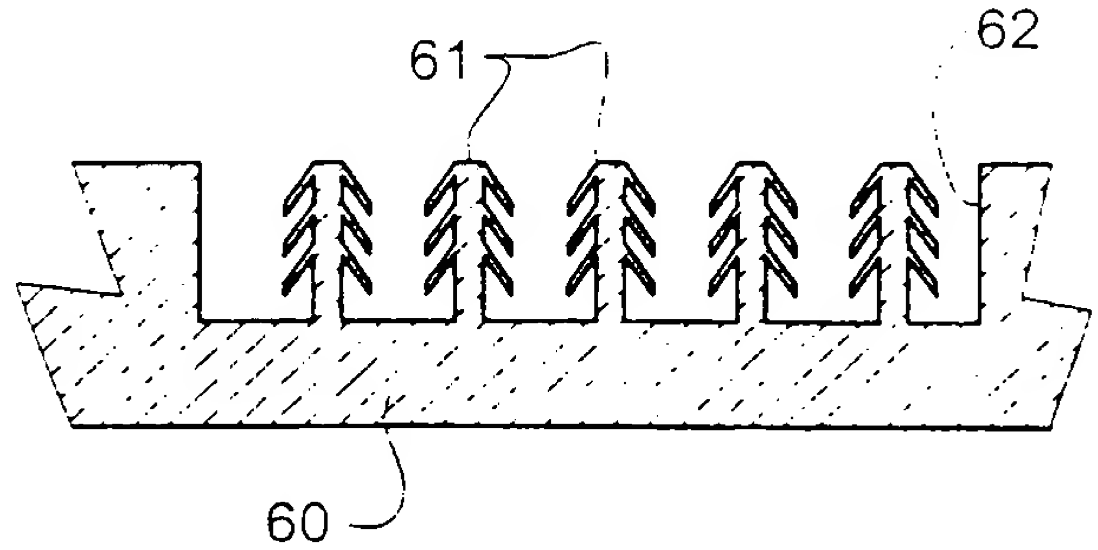

Fig. 13

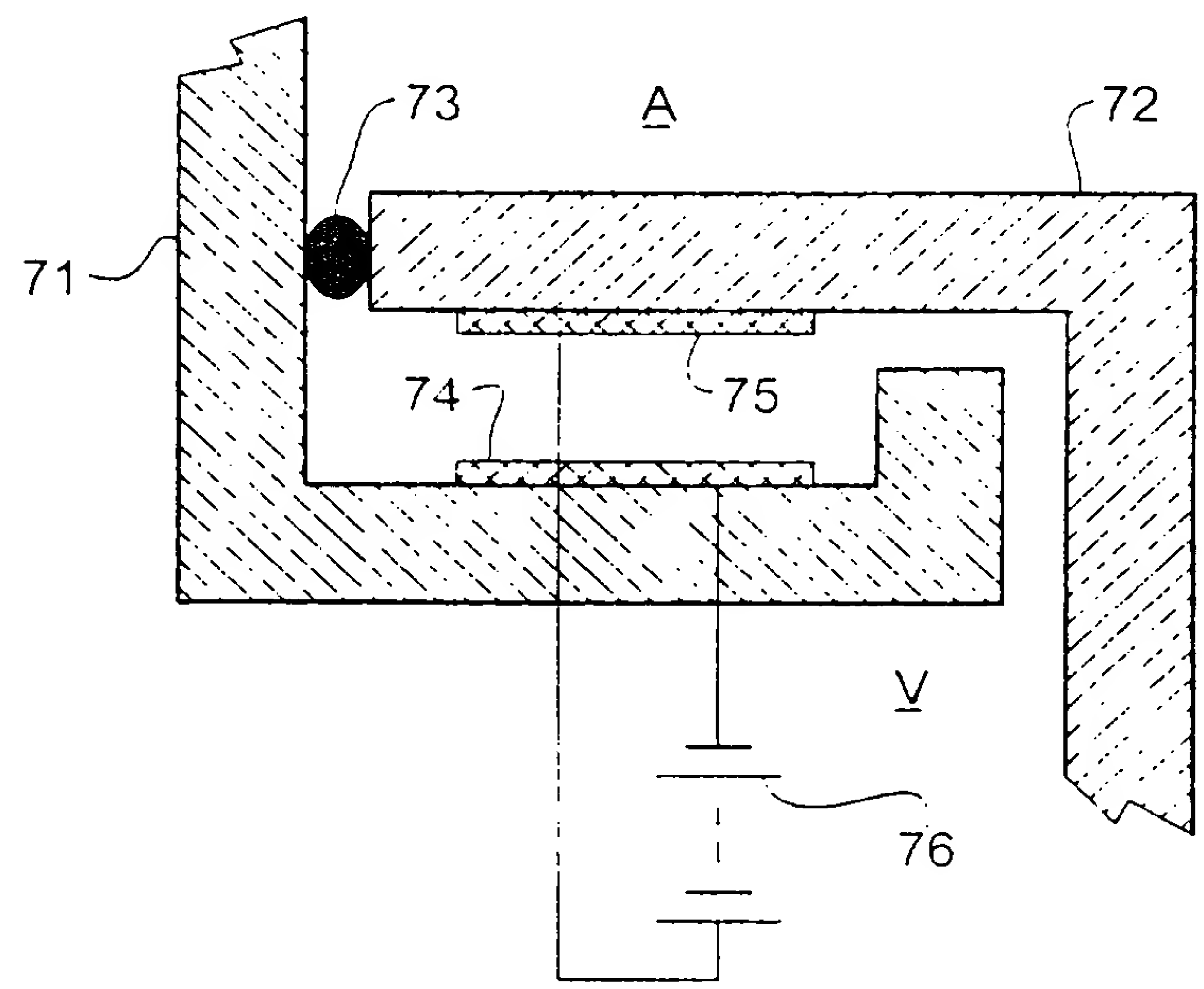

Fig. 14